

Pioneers

20. Michael Faraday (1791-1867): 'patron saint' of electrical engineers.

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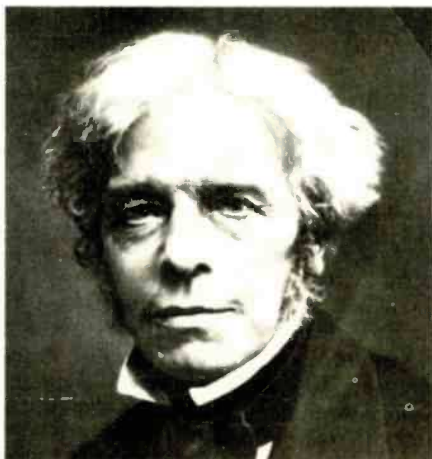
He had only an elementary education, "little more than the rudiments of reading, writing and arithmetic at a common day school", as he himself described it. Yet the Encyclopaedia Britannica has called him "possibly the greatest experimental genius the world has known". Many equally generous tributes have been paid to this unique man. He has been called the patron saint of electrical engineers and Humphry Davy's greatest discovery. The testimonial I like best, though, was spoken by a German professor, F.W. Kohlrausch, and contains just four words: "He smells the truth". The "he", of course, was Michael Faraday.

Most of Faraday's long list of scientific discoveries lie in the fields of chemistry and electricity, and they took him into some odd corners. Of his 158 published papers, about half relate to electrical science and a third to chemistry. The rest range over a variety of topics and include one, "On holding the breath for a lengthened period". Another, "Change of musket balls in shrapnel shells: Action of gunpowder on lead", almost sounds like a defence contract. Trinity House asked him to judge the viability of arc lights for lighthouses, the National Gallery in London sought his advice on the preservation of art treasures, and he was even consulted over an idea for using hydrogen sulphide for gas warfare.

His contemporaries said he was a kind, gentle and proud man who had a simple manner and attitude.

As well as being one of the world's greatest scientists he was also a committed Christian and that must say something about those who profess that science and religion do not mix. His personal faith helped shape his philosophy and led him to accept the unity of the universe and the fallibility of men. Together these encouraged him to speculate and to publish what were virtually scientific heresies – including his famous curved lines of force. From such speculations came the beginnings of electromagnetic field theory. In 1852 his agnostic friend John Tyndall wrote, "I think that a good deal of Faraday's week-day strength and persistency might be referred to his Sunday Exercises. He drinks from a fount on Sunday which refreshes his soul for a week."¹

It would be nice to think that all electrical and electronic engineers know that Faraday made what is possibly the most important discovery in electrical science: that of electromagnetic induction. (It was discovered almost simultaneously by Henry in America.) Many know that he established the basic laws of electrolysis. But his great experimental skills and persistence, and his non-mathematical reasoning, also led him



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to electromagnetic rotation (the basis of electric motors), proof that the different 'types' of electricity (frictional, electrostatic, voltaic, etc.) are manifestations of the same basic phenomena, to a new theory of electricity, the dielectric constant, the rotation of the plane of polarization of light, and the start of classical field theory and the electromagnetic theory of light. He established several of our common terms, including electrode, anode, cathode, electrolysis, electrolyte, paramagnetism and diamagnetism (which he discovered) and, I believe, dielectric. True to his character he chose these terms very carefully and with the help of William Whewell of Cambridge University.

Faraday played a major role in a pattern of experimentation and reasoning on electromagnetism and related sciences which be-

A PLEA FOR PLAIN LANGUAGE

In 1857 Faraday, aged 66, wrote to the 26-year old James Clerk Maxwell as follows:

"There is one thing I would be glad to ask you. When a mathematician engaged in investigating physical actions and results has arrived at his conclusions, may they not be expressed in common language as fully, clearly, and definitely as in mathematical formulae? If so, would it not be a great boon to such as I to express them so? – translating them out of their hieroglyphics, that we also might work upon them by experiment. I think it must be so, because I have always found that you could convey to me a perfectly clear idea of your conclusions, which, though they may give me no full understanding of the steps of your process, give me the results neither above nor below the truth, and so clear in character that I can think and work from them."

gan with Oersted and culminated with Einstein and Planck.

Besides that, chemical engineers are proud of him too – for producing higher-grade steels (1818), for making the first compounds of carbon and chlorine (the first "substitution" reactions, 1820), and for discovering benzene (1825). He was also an outstanding public lecturer: the annual IEE lecture to young people is named in his honour.

EARLY LIFE

Michael was the third of four children of James and Margaret Faraday. He was born on 22 September, 1791, at Newington, now part of Southwark in London but then in the country. His father, a blacksmith, had moved south from Yorkshire in search of work in the year that Michael was born. His ill health meant that the family was poor. Michael later recollected that he was once given a loaf of bread to sustain him for a week.

At 13 the young Michael became a newspaper delivery boy for a Mr G. Riebau, a French *émigré* who had fled the Revolution. Riebau sold books as well as newspapers, and he bound books too. Faraday was soon an apprentice bookbinder and so gained access to a large and ever-changing library.

Some of those books fired his love for science. One, Jane Marcet's "Conversations on Chemistry", remained a life-long favourite. Another, the Encyclopaedia Britannica, introduced him to electricity through an article by James Tytler, a "scientific heretic" who saw electricity as a vibration rather than as a flow of particles¹. How much this unorthodox viewpoint influenced Faraday's later approach to scientific reasoning is a matter for interesting conjecture.

Meanwhile, while Faraday bound books, a group of young men had begun to meet in London to discuss scientific topics. They called themselves the City Philosophical Society. Faraday came across them early in 1810 and their lectures extended his education. In 1812, he was able to attend public lectures given by the great Humphry Davy. The tickets were a gift from one of the bookshop's customers – someone to whom electrical engineers should be grateful, for he provided an opening which Faraday turned into a career.

In October 1812, Davy was temporarily blinded in a laboratory explosion and Faraday was recommended as a temporary help. In December Faraday sent Davy a bound volume of the notes he had taken of Davy's lectures. The next March, when the Royal Institution, at which Davy was employed, sacked a laboratory assistant for fighting, Davy recommended Faraday for employment. So began, on 1 March, 1813, an association which was to last all of Faraday's working life¹.

Thus Faraday became assistant to Davy, one of the greatest scientists of the day. The respect Davy commanded may be judged by the welcome he received in Paris when he toured the continent in 1813-14, accompanied by his wife and by Faraday. Despite the conflict between Britain and France he was given safe passage and warmly received.

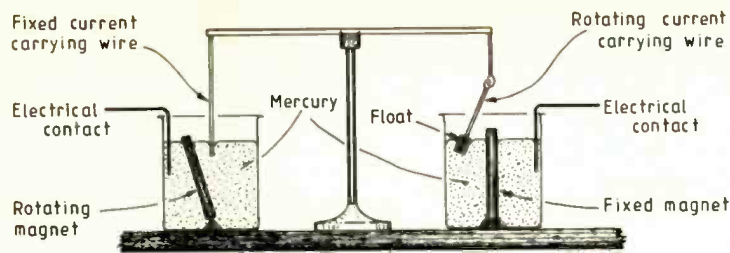


Fig.1. Faraday's apparatus for demonstrating electromagnetic rotation (simplified).

Faraday's early work at the Royal Institution was mainly concerned with chemistry. But in 1821 the editor of *The Philosophical Magazine*, a major scientific journal, asked him to review the flood of theories and experiments which had followed Oersted's discovery of electromagnetism and to separate fact from fiction. Somewhat reluctantly Faraday agreed.

His enthusiasm was soon aroused however; and, as usual, he repeated others' experiments with great care rather than merely accept their results. Whilst tackling Oersted's experiments he used a small magnetic needle to plot the pattern of the magnetic force around a current-carrying wire. He soon realised that a single magnetic pole should rotate around the wire. Figure 1 shows his elegant experiment which showed the truth of this – the first conversion of electrical energy into mechanical motion and the basis of the electric motor (3, 4 September, 1821). On Christmas Day he showed his wife Sarah (they had married that year) and his brother-in-law that a wire could be made to rotate using only the Earth's magnetism. "Do you see, do you see, do you see, George?" asked Faraday in his excitement. "I shall never forget the enthusiasm expressed in his face and the sparkling in his eyes", his brother-in-law wrote later.

This, his first great success, also brought him the unpleasant and unjust charge of stealing the idea without acknowledgement.

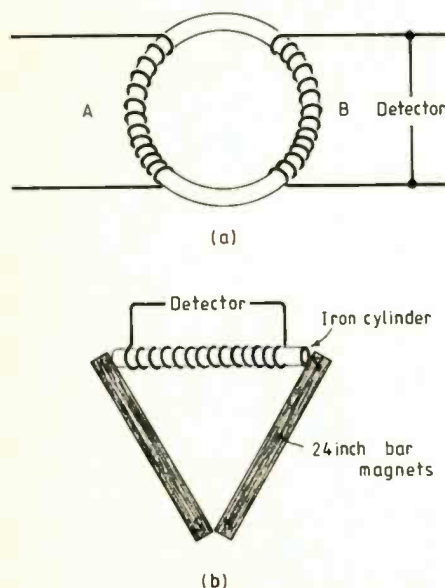


Fig.2. (a) The ring experiment, electromagnetic induction; (b) conversion of magnetism into electricity. Both 1831.

W.H. Wollaston, with Davy, had tried a somewhat similar but futile experiment some months earlier. Two years later Faraday further aroused Davy's jealousy by liquefying chlorine, something at which Davy had failed. In 1824 Davy unsuccessfully opposed Faraday's election to the Royal Society, but Faraday never repaid even this slur.

ELECTROMAGNETIC INDUCTION

Two years after Davy's death, in 1831, came Faraday's discovery of electromagnetic induction and the culmination of an 11-year search by scientists to find the reverse of Oersted's discovery: to produce electricity from magnetism.

Two coils of wire had been wound on opposite sides of a soft iron ring six inches in diameter. One coil was connected to a battery and the other to a simple galvanometer (a wire passing over a magnetic needle). Nothing happened whilst the battery was either in circuit or out of it, as others had observed previously, but the needle was deflected whenever the battery connection was made or broken. Whenever the primary current started or stopped it induced a current in the secondary. Faraday's breakthrough was the outcome of great mental exertion and very careful observation. It was 29 August, 1831.

One 24 September, magnetism was converted into electricity. A wire helix was wrapped around an iron cylinder and the wires led off to a current detector. Two 24-inch bar magnets were placed so as to magnetize the iron cylinder. Whenever the magnetic circuit was made or broken a momentary current was generated. Later a current was generated by pushing a bar magnet into and out of a wire helix.

Faraday reported his results to the Royal Society in London and to the Academy of Sciences in Paris. Soon small hand-driven magneto generators were being produced by others. Gauss and Weber used one to power their experimental electromagnetic telegraph from 1835.

Precisely what process of thought led Faraday to near-perfect experiments for these discoveries is a matter for historical detective work.

It is known that Faraday was unhappy with the contemporary theories of electricity and magnetism and in particular with the concept that electric current is a simple flow of particles. He believed that the presence of what we now call electric or magnetic fields put the conducting medium into a state of strain. His lines of force represented the lines of strain. Vibrations in those lines

would somehow transfer energy without transferring matter. In parallel with this he took an interest in acoustics, especially in making flat plates vibrate in resonance to other vibrating plates – a sort of acoustical induction. He studied this topic up to just six weeks before his discovery of electromagnetic induction. Almost certainly he saw an analogy between acoustics and electricity.

Later he developed his ideas into a general theory of electricity and even extended them into a probing attack on the transmission of light through a vacuum ("Thoughts on ray vibrations", 1846). Here he saw radiation as a "high species of vibration in the lines of force". Later (1852) he speculated that lines of magnetic force existed as strains, not in material bodies, but in "the condition of space free from such material particles". Many historians of science see Faraday's "Thought on ray vibrations" as the embryonic form of Maxwell's electromagnetic theory of light. Indeed Maxwell's first paper of the series which led to his theory was a mathematical treatment of Faraday's lines of force.

Faraday, whose education equipped him with almost no mathematical skills, commented, "I was at first almost frightened when I saw such mathematical force made to bear on the subject, and then wondered to see that the subject stood it so well". He even wrote to the young Maxwell praising his skills at translating mathematics into clear everyday English.

By the late 1830s Faraday himself had been strained to the limit by his mental exertions and he suffered what has variously been called exhaustion or a nervous or mental breakdown. It has also been suggested that he was being slowly poisoned by the mercury he used for electrical connections. It was five years before he fully recovered, if indeed he ever did fully recover.

Between 1861 and 1865 Michael Faraday retired from his various duties and spent his remaining years under royal patronage in a house provided by Queen Victoria near Hampton Court. Since his illness of the late 1830s he had suffered increasingly from intermittent loss of memory. His last few years were spent in a state of mental confusion. He died on 25 August, 1867.

His ability to "smell the truth" led him to search without success for other physical phenomena which he believed to exist. Many of these have since been found, including magnetostriction and the Kerr and Zeeman effects. Another, a link between electricity and gravity, we have yet to find. Maybe one day it will become yet another Faraday Effect!

References

1. Dictionary of Scientific Biography.
2. P. Dunsheath, "A history of electrical engineering", Faber, 1962.
3. L.P. Williams, "Michael Faraday", Chapman & Hall, London 1965. (See also a summary in W.A. Atherton, "From Compass to Computer, a history of electrical and electronic engineering", Macmillan, 1984).

Next in this series of pioneers of electrical communication: Alec Reeves, inventor of pulse code modulation.